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NUCLEAR FUSION RESONANCE REACTIONS OF POSSIBLE CTR INTEREST

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J. Rand McNally, Jr.

Abstract

Some speculations are presented on possible nuclear fusion resonance reactions which may be of importance to the development of "clean" controlled thermonuclear reactors of either toroidal or mirror type.

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Crocker, Blow and Watson recently pointed out[1] that a nuclear "reaction with a large resonance cross-section below about 1 MeV might be of interest" to CTR. Over three years ago I compiled a list of potential fusion reactions having such low energy resonances. The $D + T \rightarrow {}^{5}He^{*} \rightarrow n + \alpha$ and $D + {}^{3}He \rightarrow {}^{5}Li^{*} \rightarrow p + \alpha$ are notable and well known examples of such resonances via the formation of a short-lived compound nucleus. However, other resonance types may also be of importance such as when one (or both) of the product nuclei is formed in an excited nuclear state. The excited state may decay by energetic particle emission or by a gamma ray transition to the ground state nucleus. Energy Levels of Light Nuclei[2] are essential to the discovery of such resonances.

Table I lists various "resonance" reactions but is quite incomplete, especially if one includes bombarding energies up to 1 MeV. To be truly a resonance reaction certain quantum rules must be satisfied, the reaction must be slightly endothermic (or Γ overlap the low energy region when ΔQ is positive) and the particle kinetic energy to give resonance must provide $- \Delta Q$ in the center of mass system. It would appear that many of these resonance reactions at low bombarding energy have not been studied because researchers did not go to low enough energies or may not have looked for the right particle emission.

Inasmuch as Tokamaks may give very high ion temperatures for impurities (Alpha and Zeta gave T_{+} up to 1.3 keV for O^{5+})[3] it may be appropriate to look into this field of resonance reactions more closely. The high density Burnout V plasma also gives interesting ion temperatures (~ 3 keV) for C^+, N^+, O^+, and Cu^+.[4] Such a view would necessarily entail encouraging very low energy nuclear collision physics research (<< 1 MeV) for which many university laboratories are probably equipped. These cross sections are low on the Gamow curve but one should remember that the D•T resonance at about 100 keV gives a one-hundred fold larger cross section than the D•D non-resonance reactions. The discovery of a useful nuclear resonance at low energies (and having energetic charged particle production and/or gamma rays only) might lead to a "clean" CTR, i.e., one having no neutron production or long-lived radioactive products. As an example from Table I, we have $^{12}C + d \rightarrow {}^{14}N^*(10.24)$ which can decay to $^{13}C + p + 10.24 - 7.55$ or $Q = 2.69$ MeV in non-radioactive charged particles which could sustain the reaction [the $^{14}N^*$ state at 10.43 MeV has a ΔQ (for $^{12}C + d$) of -165 keV with $\Gamma = 28$ keV; however, this would require a higher fusion temperature for resonance and hence D•D reactions would also occur with the possibly adverse production of neutrons and tritons].

Experimental research on these and other possible low energy resonances may reveal important processes which would benefit the CTR program.

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TABLE I. NUCLEAR REACTIONS HAVING LOW ENERGY NUCLEAR RESONANCES

REACTION	Energy Defect ΔQ**(keV)	State Width Γ(keV)	σ(at peak)
$D + T \rightarrow {}^{5}He^{*}(16.69\ MeV)$	- 61	80	5000 mb.
$D + {}^{3}He \rightarrow {}^{5}Li^{*}(16.81)$	- 255	300	800
${}^{7}Li + d \rightarrow {}^{9}Be^{*}(16.674)$	+ 19	42	?
${}^{9}Be + p \rightarrow {}^{10}B^{*}(6.566)$	+ 21	~70	?
${}^{9}Be + {}^{3}He \rightarrow {}^{11}B^{*}(10.32) + p$	+ 5?	45	?
${}^{9}Be + {}^{3}He \rightarrow {}^{8}Be^{*}(18.94) + \alpha$	+ 11	?	?
${}^{9}Be + {}^{3}He \rightarrow {}^{7}Be + n + \alpha$	+ 16	0	?
${}^{10}B + {}^{3}He \rightarrow {}^{12}C^{*}(19.67) + p$	+ 31	180	?
${}^{11}B + p \rightarrow {}^{12}C^{*}(16.11)$	- 152	6	10
${}^{11}B + p \rightarrow {}^{12}C^{*}(16.58)$	- 622	150	600
${}^{12}C + p \rightarrow {}^{13}N^{*}(2.365)$	- 424	?	127
${}^{12}C + d \rightarrow {}^{14}N^{*}(10.24)$	+ 25	75	?
${}^{12}C + d \rightarrow {}^{14}N^{*}(10.43)$	- 165	28	?
${}^{13}C + p \rightarrow {}^{14}N^{*}(7.60)$	- 54	small?	?
${}^{13}C + d \rightarrow {}^{15}N^{*}(16.04)$	+ 121	?	?
${}^{13}C + {}^{3}He \rightarrow {}^{12}C^{*}(15.632) + \alpha$	+ 12?	?	?
${}^{14}N + d \rightarrow {}^{15}O^{*}\left\{\begin{matrix}5.195\\5.247\end{matrix}\right\} + n$	- 122 - 174	3×10^{-6}	?
${}^{14}N + d \rightarrow {}^{15}N^{*}(8.575) + p$	+ 40	small?	?
${}^{14}N + {}^{3}He \rightarrow {}^{16}O^{*}\left\{\begin{matrix}15.25\\15.21\end{matrix}\right\} + p$	- 15 + 25	720 72	? ?
${}^{15}N + p \rightarrow {}^{16}O^{*}(12.515)$	- 402	?	200
${}^{14}N + {}^{14}N \rightarrow {}^{12}C^{*}(4.43) + {}^{16}O^{*}(6.06)$	- 26	very small	?
${}^{14}N + {}^{14}N \rightarrow {}^{12}C^{*}(4.43) + {}^{16}O^{*}(6.14)$	- 34	very small	?

TABLE I. NUCLEAR REACTIONS HAVING LOW ENERGY NUCLEAR RESONANCES

REACTION	Energy Defect ΔQ^{**}(keV)	State Width Γ(keV)	σ(at peak)
$^{15}N + d \rightarrow$ $^{16}O^{*}(9.886) + n$	+ 43	0.8	?
$^{15}N + d \rightarrow$ $^{16}N^{*}(0.392) + p$	- 125	?	?
$^{15}N + d \rightarrow$ $^{16}N^{*}(0.295) + p$	- 28	?	?
$^{15}N + d \rightarrow$ $^{16}N^{*}(0.120) + p$	+ 147	10^{-12}	?
$^{15}N + {}^{3}He \rightarrow$ $^{17}O^{*}(8.59) + p$	- 52	?	?
$^{15}N + {}^{3}He \rightarrow$ $^{14}N^{*}(9.736) + \alpha$	+ 26	14	?
$^{17}O + d \rightarrow {}^{18}F^{*}(3.354) + n$	+ 38	?	?
$^{17}O + {}^{3}He \rightarrow {}^{16}O^{*}(16.44) + \alpha$	- 8	24	?

*Excited state with excess energy given in parentheses in MeV. Various decays are possible (see ref. 2).

**When ΔQ negative, this energy must be provided in center of mass. When ΔQ is positive, the state half-width Γ must overlap the low energy collision region.